Cut Methane, Grow More Food

Cleaner air. Greater harvests. Safer climate.

Ground-level ozone is an invisible air pollutant that causes significant damage to crops worldwide. Tackling methane emissions, one of the precursors, could be the key to curbing rising background levels of ozone.

More than a greenhouse gas

Methane is primarily known as a potent greenhouse gas that drives global warming. However, its role in the formation of ground-level ozone is less widely recognized. Ground-level ozone (O_3) forms through a chemical reaction where methane (CH_4), carbon monoxide (CO), and volatile organic compounds (VOCs) react with nitrogen oxides (NOx) under the influence of sunlight's UV radiation. This reactive gas is not only harmful to human health but also causes extensive damage to plants and ecosystems.

However ozone also damages agricultural crops – and it's no small matter. According to the World Meteorological Organization (WMO), global crop losses due to ozone damage between 2010 and 2012 were estimated at around 12.4% for soybeans, 7.1% for wheat, 4.4% for rice, and 6.1% for maize. Amounting to a total 227 million tonnes in losses for these four staple crops, this has a substantial impact both on local economies and global food security. [1]

PHOTO: U.S. NARA - PUBLIC DOMAIN

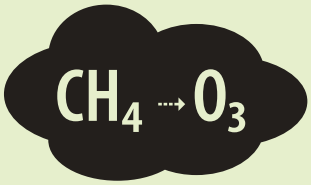
Typical ozone damage on bean leaves.

The problem is global

The extent of its impact is a combination of climatic conditions, regional pollution levels, and type of agricultural production. WMO has identified several particularly vulnerable regions. In the US, multiple states along the West Coast, as well as central and northeastern regions, are heavily affected, along with southern Canada. Eastern China, Korea, Japan, and parts of India are also hotspots.

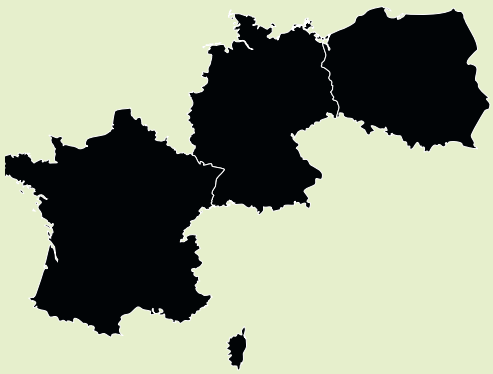
In Europe, ozone levels are highest in the Mediterranean region, yet ozone damage affects most agricultural areas across the continent. According to a 2022 EU study [2], nine member states lost more than five percent of their wheat yield, and eleven experienced similar losses for potatoes. Poland was the hardest hit, losing 10% of its potato yield to ozone, while Belgium saw wheat losses exceeding 7%. In absolute terms, the largest losses occurred in major producing countries such as France, Germany, Poland, and the Netherlands. And 2022 was not an exceptional year – ozone levels were fairly typical.

Plant sensitivity to ozone has been known since the 1950s [3]. Researchers in California observed plant damage linked to local smog containing ozone. Plants absorb ozone through their stomata while simultaneously taking in carbon



Methane is not only a potent greenhouse gas – it drives ground-level ozone that damages crops.

Ozone causes annual yield losses of 2-10 % in most EU countries [2].



In 2022 absolute losses in wheat production were highest in France with 2.5 million tonnes of lost production, followed by Germany (1.4 million tonnes), and Poland (465 thousand tonnes) [2].

dioxide for photosynthesis. Once inside plant cells, ozone can cause significant damage, especially when the plant's natural antioxidants, which act as a first line of defence, are depleted. This leads to impaired photosynthesis, reduced growth, and often smaller seeds with lower nutritional content. In legumes, nitrogen fixation ability also declines, which may explain why soybeans are the most sensitive to ozone among major crops. Ozone thresholds are typically expressed in AOT40, but PODY is another indicator that is becoming more widely used (see box).

Rising background ozone

In recent decades, ground-level ozone levels have shown varied trends [1]. Thanks to reduced emissions of nitrogen oxides and volatile organic compounds, the most extreme ozone peaks have levelled off. At the same time, background ozone levels have increased globally, largely due to rising methane concentrations in the atmosphere and climate change. Methane, with an average atmospheric lifespan of about 12 years, is considered a short-lived greenhouse gas. However, compared to other ozone-forming substances that have lifespans of only days or weeks, methane persists much longer, giving it a global impact on ozone levels, unlike NOx and other precursors, which mainly have local-regional effects. [4]

The environmental costs of methane emissions have typically been calculated based on their impact on climate and public health, a concept known as the "social cost of methane". A 2023 study shows that if ozone damage to crops is also factored in, the marginal cost of methane emissions could increase by an additional 15–30%, or 423–556 USD per ton [4].

An invisible problem for farmers

Ground-level ozone is somewhat of an under-the-radar issue when it comes to air pollution, and its impact on crops is mostly recognised by a few researchers and experts in government agencies. Most farmers do not associate lower crop yields with the colourless gas formed on sunny days. Brown spots on leaves are often mistaken for drought stress or pest damage.

Likewise, farmers are unaware that improved air quality reduces such damage. Let's return to California, where the problem was first identified. Between 1980 and 2015, air quality improved significantly there, and according to one study, this cleaner air led to an annual increase in fruit and nut yields worth 600 million USD [5]. In a local newspaper [6], one of the researchers behind the study, Steven Davis, was interviewed: "A lot of California farmers may not appreciate that air quality standards have had such a benefit on their ability to grow crops," he said, continuing, "The irony is that by fighting against certain environmental regulations, these folks may be damaging their own earning capacity".

[1] World Meteorological Organization (2023). The Impacts of Tropospheric Ozone Pollution on Crop Yield: Mechanisms, Quantification and Options for Mitigation https://library.wmo.int/idurl/4/68654

[2] Schucht, S., Tognet, F., Létinois, L. (2024), Wheat and potato yield loss in 2022 in Europe due to ozone exposure (Eionet Report –ETC HE 2024/9). European Topic Centre on Human Health and the Environment

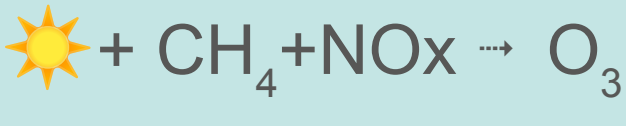
[3] Agathokleous, Evgenios & Saitanis, Costas. (2023). Effects of Ozone on Forests. 10.1007/978-981-15-2760-9_24.

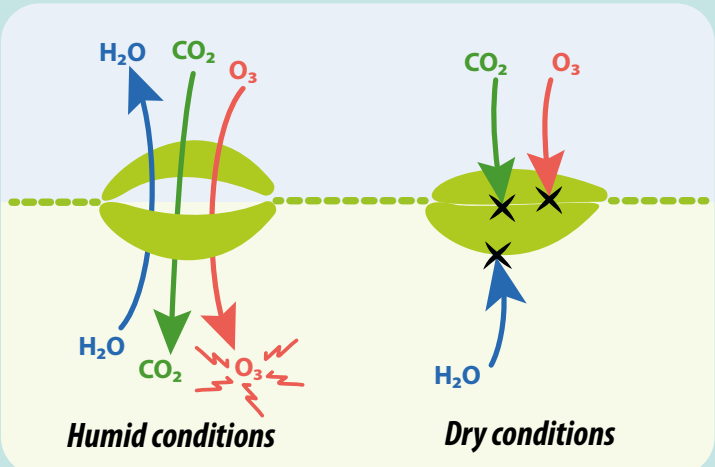
[4] Sampedro, Jon & Waldhoff, Stephanie & Sarofim, Marcus & Van Dingenen, Rita. (2023). Marginal Damage of Methane Emissions: Ozone Impacts on Agriculture. Environmental and Resource Economics. 84. 1-32. 10.1007/s10640-022-00750-6.

[5] Hong, Chaopeng & Mueller, Nathaniel & Burney, Jennifer & Zhang, Yang & Agha-Kouchak, Amir & Moore, Frances & Qin, Yue & Tong, Dan & Davis, Steven. (2020). Impacts of ozone and climate change on yields of perennial crops in California. Nature Food. 1. 10.1038/s43016-020-0043-8.

[6] UC San Diego Today, March 19, 2020, California's Strict Air Quality Regulations Help Farmers Prosper. https://today.ucsd.edu/story/californias-strict-air-quality-regulations-...

How methane drives ozone and crop damage





Ground-level ozone (O_3) forms through a chemical reaction where methane (CH_4), carbon monoxide (CO), and volatile organic compounds (VOCs) react with nitrogen oxides (NOx) under the influence of sunlight's UV radiation.

Plants absorb ozone through their stomata – the same tiny pores they use to take in carbon dioxide for photosynthesis. Once inside the cells, ozone causes oxidative damage. If the plant's natural antioxidants are depleted, this leads to impaired photosynthesis, reduced growth, and smaller seeds with lower nutritional value. Under dry conditions, plants close their stomata to conserve water – which also makes them less exposed to ozone, though at the cost of reduced photosynthesis.

Methods to assess crop loss from ozone

There are several methods for assessing the risk of ozone damage to crops, with the most widely used being AOTX (Accumulated Ozone Exposure over a Threshold of X ppb). This method calculates ozone exposure during daytime hours over the course of a growing season. In Europe, the growing season for crops is typically defined as May through July. The most common threshold, referred to as AOT40, is set at 40 ppb. Under the EU's air quality directive, there are two specific targets for ozone exposure on agricultural land:

- A target value where AOT40 is 18,000 (µg/m^3).hour, averaged over 5 years.
- A long-term goal where AOT40 should be below 6,000 (µg/m^3). hour by January 1, 2050.

In 2022, 10 member states met the target for all agricultural land, and only four member states (Finland, Ireland, Latvia, and Lithuania) met the long-term goal. [7]

However, research has shown that significantly lower levels, down to 20–25 ppb, can cause damage. This means that AOT40 underestimates the actual risks, suggesting that lower threshold values, such as AOT25, would be a better indicator.

A more biologically accurate method for assessing risks is to measure how much ozone plants actually absorb. This measure is called Phytotoxic Ozone Dose (PODY), and it takes into account how a plant's ozone uptake varies depending on the size of its stomata, weather conditions, and other environmental factors. Different threshold values (Y) are used for different plant types and vegetation; for example, Y=6 is used for wheat. [8]

ICP Vegetation [9], which developed the POD method, has also established specific critical threshold values for different species and vegetation types. The critical level for wheat (where yield is reduced by 5%) is set at an ozone uptake of 1.3 mmol/m^2 during a growing season, while the corresponding value for potatoes is 3.6 mmol/m^2. The EU has not formulated any targets based on PODY. However, member states are required to assess and report exceedances of critical PODY levels for crops like wheat, tomatoes, and potatoes. [10, 11]

In summary: The advantage of the AOTX method is that it is simple and flexible since all you need are hourly ozone measurements. To calculate PODY, meteorological data is also required, but it provides more accurate estimates of the risk of ozone damage.

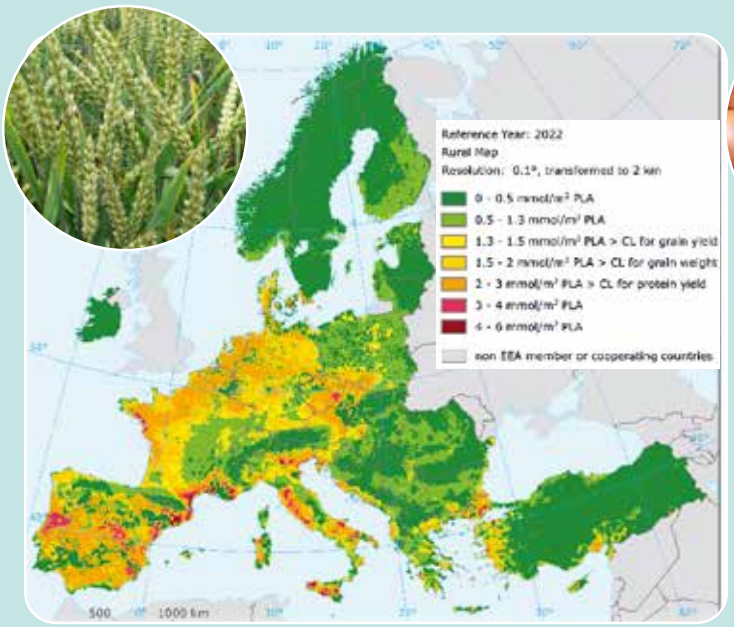
[7] European Environment Agency, 24 June 2024, Exposure of Europe's ecosystems to ozone

[8] Håkan Pleijel, Helena Danielsson, Malin C. Broberg, Benefits of the Phytotoxic Ozone Dose (POD) index in dose-response functions for wheat yield loss, Atmospheric Environment, Volume 268, 2022, 118797, ISSN 1352-2310.

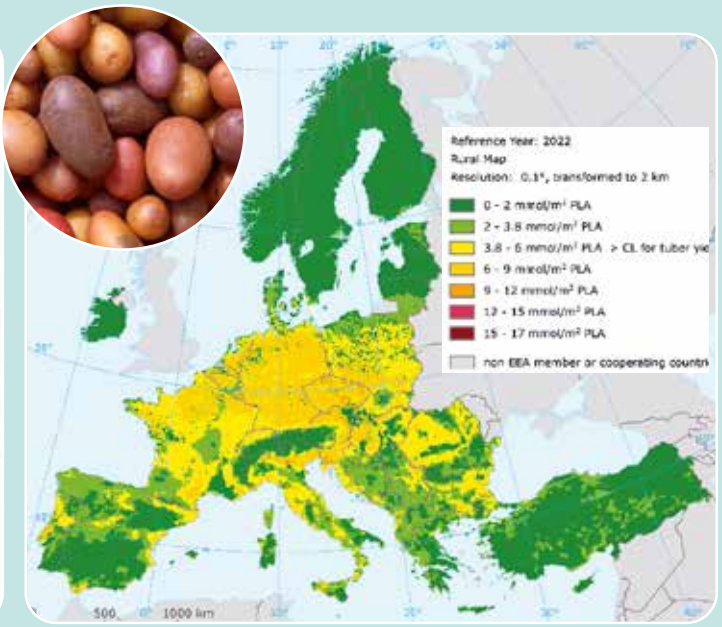
[9] Vegetation, ICP; Mills, G., Harmens, H., Hayes, F., Pleijel, H., Büker, P. & González, I. (2017). Flux-based critical levels of ozone pollution for vegetation: Overview of new developments 2017.

[10] Communication from the Commission – Commission Notice on ecosystem monitoring under Article 9 and Annex V of Directive (EU) 2016/2284 of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants (NEC-Directive)

[11] Convention, LRTAP, Mills, G., Harmens, H., Hayes, F., Pleijel, H., Büker, P., González, I., Alonso, R., Bender, J., Bergmann, E., & Bermejo, V., Braun, S., Danielsson, H., Gerosa, G., Grünhage, L., Karlsson, P., Marzuoli, R., Schaub, M. & Simpson, D. (2017). MAPPING CRITICAL LEVELS FOR VEGETATION Revised Chapter 3 of the Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends.



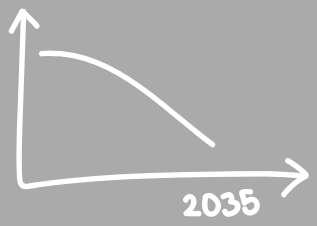
Ozone flux, POD6, for wheat in 2022, green areas are below critical levels for grain yield.



Ozone flux, POD6, for potato in 2022, green areas are below critical levels for tuber yield.

Source: Eionet Report – ETC HE 2024/4 CC BY 4.0 DOI:10.5281/zenodo.14639622 Photo: David Monniaux CC BY-SA and Scott Bauer USDA/Public Domain

Why action on methane delivers rapid results



- Methane remains in the atmosphere for only about 12 years, so reductions lead to measurable **benefits within a decade.**
- Unlike many other ozone-forming pollutants, methane emissions have not fallen as much, leaving large, **cost-effective mitigation opportunities.**
- Stronger methane policies are a **win-win for agriculture, food security, public health, and the climate.**

Policy recommendations

- Set binding EU and national methane-reduction **targets**, supported by comprehensive Methane **Action Plans** that address all major sources.
- Ensure binding reduction measures **include agriculture**, the largest emitting sector.
- Phase out the landfilling of untreated waste and strengthen bio-waste collection to **limit methane formation from organic waste**.
- Strengthen the **EU Methane Regulation** through robust implementation and delegated acts to effectively address the methane emissions linked to fossil fuel imports.
- Integrate methane into air-quality legislation, including the **the NEC Directive and the UNECE Gothenburg Protocol,** recognising its role as a key ozone precursor.
- **Update ozone exposure targets for agricultural land** by replacing AOT40 with the more scientifically robust PODY flux metric.
- **Account for ozone-related crop losses** when calculating the social cost for methane.
- Encourage and support strong **international efforts to reduce methane globally.**